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COMPARATIVE STUDY OF THE INNERVATION OF THE FACIAL DISC OF SELECTED MAMMALS

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The greatest concentration of sensory nerves in the muzzle and facial disc of mammals is in the nose. In most nocturnal mammals, these nerves penetrate the epidermis of the naked nose either singly or in bundles which resemble the corpuscles of Eimer. The hair follicles around the nose, lips, and eyes, as well as the heavily innervated vibrissae follicles found in all hairy mammals except man, are well innervated; those elsewhere are not. Everywhere on the human body both large and small follicles abound in sensory nerves. These morphologic observations suggest that in most mammals the most sensitive areas of the skin are at the anterior and posterior ends (not reported here), and that human skin is better equipped for cutaneous sensibility than that of any other mammal.

In this paper we report our observations on the innervation of the epidermis and hair follicles in the facial disc of various animals, including man. The greatest concentration of nerves in epidermis and hair follicles, particularly in nocturnal animals, is at the anterior end—the nose—and gradually decreases posteriorly. All hairy mammals except man have heavily innervated sinus hair follicles, which are larger and more numerous in nocturnal than in diurnal animals. With the possible exception of the mole [1], man is the only mammal all of whose hair follicles, large or small, abound in sensory nerves, even those minuscule follicles on the nose which are appendages of sebaceous follicles. Thus, despite their reduced size nearly everywhere on the body, man's hair follicles have made his skin the most responsive mammalian epidermis to external stimuli.

Mammals with a naked rhinarium also have variable quantities of intraepidermal nerves. Numerous and characteristically arranged in jug-shaped bundles in moles, they form parallel bundles in tree shrews, lorises, and opossums; they appear in branched fibers in the snout of the pig and the trunk of elephants and in solitary unit fibers in rodents, felines, canines, and other animals. Numerous häarscheiben were found on the nose of Cercopithecoid primates.

To avoid confusion, we will briefly describe the innervation of the muzzles of 10 species of mammals separately and then draw some conclusions about their differences and similarities.

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MATERIALS AND METHODS

The tissues used for these observations have been collected for a number of years immediately after death. For each animal described, we have had at least 3 specimens. In the case of the elephant, we had specimens from an infant and a half-grown animal. The observations on human tissues were made on 5 samples from the victims of accidental death. Samples of each tissue were treated with the silver method of Winkelmann and Schmit [2] and the cholinesterase techniques modified by Roman, Ford, and Montagna [3]. No attempt was made to distinguish precisely between true and pseudocholinesterases.

RESULTS

Opossum (Didelphis virginiana)

The outer surface of the rhinarium is crisscrossed by shallow incisures that form islands of different shapes which have corresponding mounds on the undersurface of the epidermis. The intraepidermal nerves that penetrate these epidermal pegs and the expanded nerve endings that form a nest at the base of the epithelial mounds have already been described [4,5,6]. From the tangle of myelinated nerve fibers at the base of the epithelial columns emerge one or more nerve trunks. Expanded nerve endings from the basal nest extend for various distances over the surface of the epidermis and stop abruptly in a blunt end. Other nerves from the same source lose their myelin sheath and penetrate the epidermis as fine, often wavy or kinky, long fibers, some of which extend to the stratum granulosum. Whereas intraepidermal nerves are found everywhere in the epidermal pegs, the longest ones are concentrated in their centers. All of the nerves mentioned above are strongly reactive for both acetylcholinesterase and butyrylcholinesterase, and all are argyrophilic (Fig. 1).

The small hair follicles immediately around the naked rhinarium are all richly innervated. However, only a few of the more lateral and posterior

FIG. 1. Argyrophilic intraepidermal neurites in the snout of the opossum. The nerves arise directly from the network of myelinated nerves at the base of the epithelial column. They tend to congregate toward the center of the epithelial mound. Compare with Figures 2 and 5. (Silver method of Winkelmann and Schmit [2], ~ 390×.)

follicles have a good supply of nerves. All of the sinus follicles, large or small, are surrounded by nerves inside the collagenous capsule. Only some of the follicles over the rest of the body have nerves around them, except those in the perineum, which resemble those around the rhinarium.

Mole (Scapanus townsendii)

The surface of the glabrous nose is incised at the front by sulci between which islands of epidermis continue as columns into the dermis. At the sides, where the rhinarium has a smooth surface, the epidermis is penetrated by single or loose bundles of neurites. A few intraepidermal neurites also penetrate the epidermis of the sparsely haired skin lateral to the nose. In front, at the base of each epidermal column, is a network of myelinated nerves and long and short expanded nerve endings which resemble those of the opposum. Nonmyelinated neurites from these nerve baskets enter the entire base of the epidermal pegs, but only those in the very center go straight up to the granular layer. The ones from the sides converge toward the center bundle and proceed upward, parallel to them, in a tight bundle of wavy fibers. The pattern outlined by these intraepidermal neurites resembles a tall, cylindrical vase with an expanded base (Fig. 2), typical of an organ of Eimer. All of these nerves are reactive for both acetylcholinesterase and butyrylcholinesterase [1]. The large deposits of reactive products in the expanded free endings and the redundant myelinated nerves diffuse away from these structures and make them look larger than they are. These and all other nerves described here are reactive for cholinesterases and are also distinctly argyrophilic (Fig. 2).

All of the hair follicles from around the rhinarium to the eyes, particularly the sinus hair follicles, are abundantly innervated. Beyond the facial disc, most follicles continue to be innervated but the nerves around them are scarce, except in the perineum where they resemble those on the snout.

Tree Shrew (Tupaia glis)

We agree with most systematists that these strange animals belong to the Prosimii. They have an elongated, pointed muzzle covered near the nose with sparse, short hairs interspersed with long vibrissae. The large rhinarium has an irregular surface, like that of the two animals just described, with corresponding rounded pegs of epidermis on the underside. The dermis beneath the shrew rhinarium, like that of the mole, is overcrowded with large, criss-crossing myelinated nerves whose branches are attached to the nerve baskets at the base of the epidermal mounds (Fig. 3).

Expanded nerve endings and myelinated fibers form nerve nets similar to those in opossums and

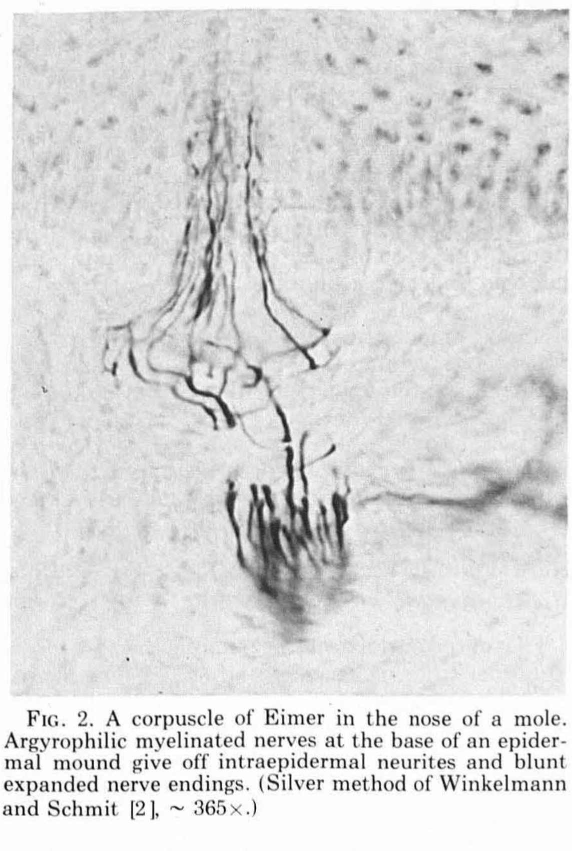

FIG. 2. A corpuscle of Eimer in the nose of a mole. Argyrophilic myelinated nerves at the base of an epidermal mound give off intraepidermal neurites and blunt expanded nerve endings. (Silver method of Winkelmann and Schmit [2], ~ 365×.)

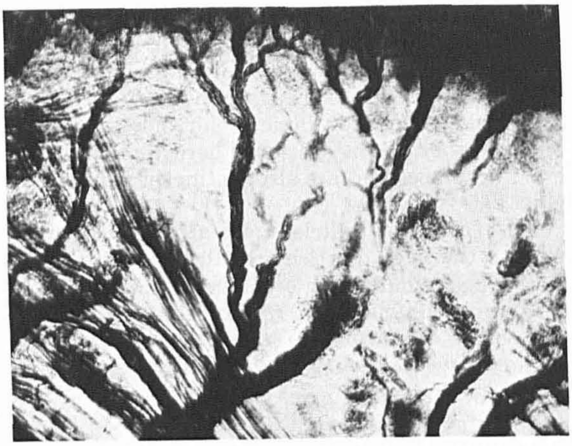

FIG. 3. Huge myelinated nerves underneath the rhinarium of a tree shrew. (Silver method of Winkelmann and Schmit [2], ~ 78×.)

moles and resemble stemmed chalices from which emerge numerous neurites that penetrate the epidermis up to the horny layer (Fig. 4). These neurites also tend to be longer and more densely concentrated in the center of the epidermal columns (Fig. 5). All of these nerves are reactive for cholinesterases and are argyrophilic.

The hair follicles on the muzzle, like those in the opossum, have numerous nerves around them (Fig. 6).

Potto (Perodicticus potto), Galago (Galago crassicaudatus), Slow Loris (Nycticebus coucang)

The rhinaria of these three species of prosimians, like the nerves associated with them, are similar. In all three species, the glabrous nose has a pebbled outer surface, with corresponding columns of epithelium which project into the dermis. The lower half to two-thirds of the epithelial columns is surrounded by myelinated nerve networks of variable density and tightness. Nearly everywhere around the base of the epithelial columns are enlarged free nerve endings of different lengths, and galagos also have glomerate bodies which resemble mucocutaneous end-organs (Fig. 7). Some nonmyelinated neurites extend for some distance into the epidermis. The nerves described here, myelinated or not, are all cholinesterase reactive.

As in the other animals described here, the hair follicles around the nose are all abundantly innervated but those over the body are not.

Macaques (Macaca mulatta, M. speciosa, and M. fascicularis)

The outer surface of the simian primate nose (suborder Cercopithecoidea) and the inside of the choanae are hairy. In most species, as in man, these hairs are small and associated with large sebaceous glands. In all three species of macaque, we have found relatively numerous cholinesterase-

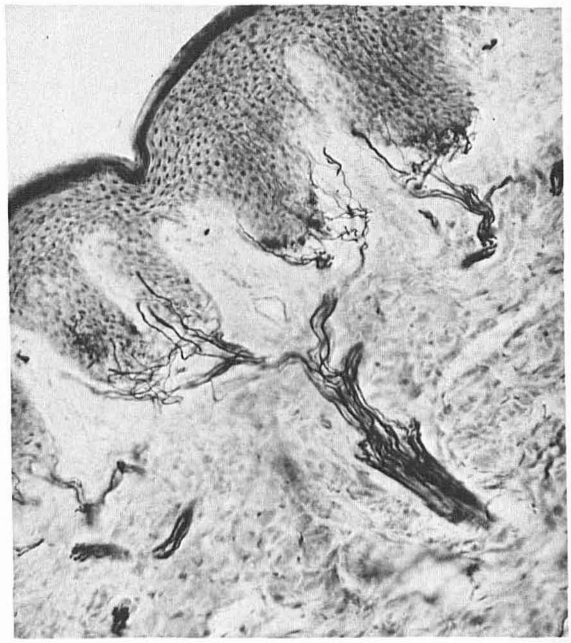

FIG. 4. Myelinated nerve baskets with expanded nerve ends at the base of three epidermal mounds from the rhinarium of a tree shrew. The intraepidermal neurites are mostly out of focus. They can be seen clearly in Figure 5. (Silver method of Winkelmann and Schmit [2], ~ 100×.)

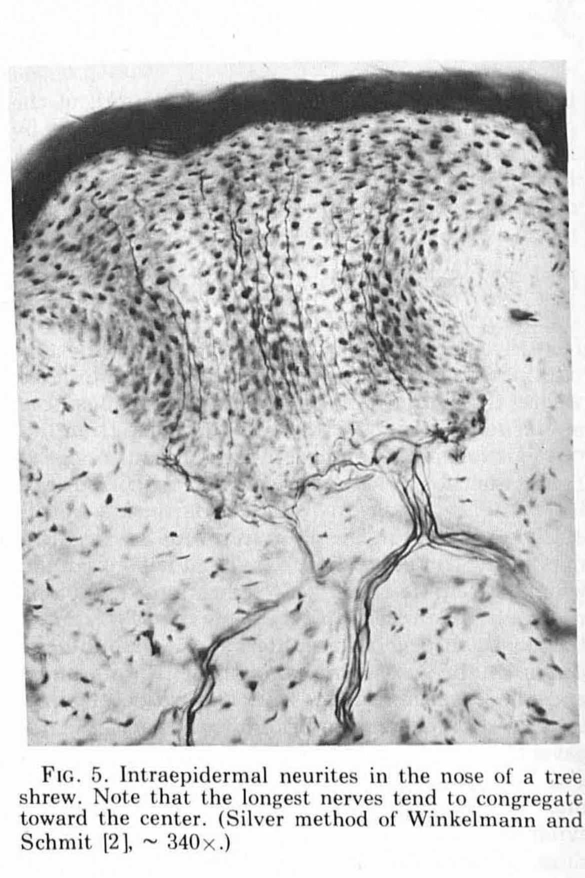

FIG. 5. Intraepidermal neurites in the nose of a tree shrew. Note that the longest nerves tend to congregate toward the center. (Silver method of Winkelmann and Schmit [2], ~ 340×.)

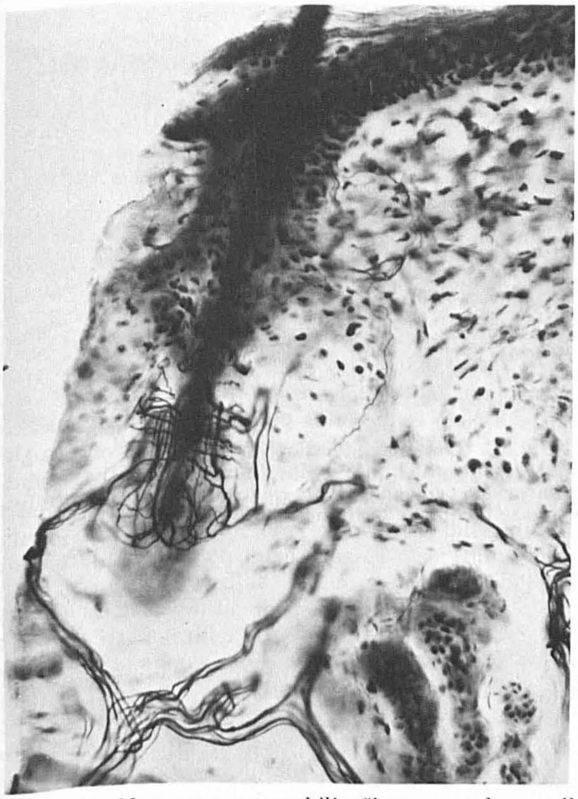

FIG. 6. Numerous argyrophilic fibers around a small hair follicle on the muzzle of a tree shrew. (Silver method of Winkelmann and Schmit [2], ~ 390×.)

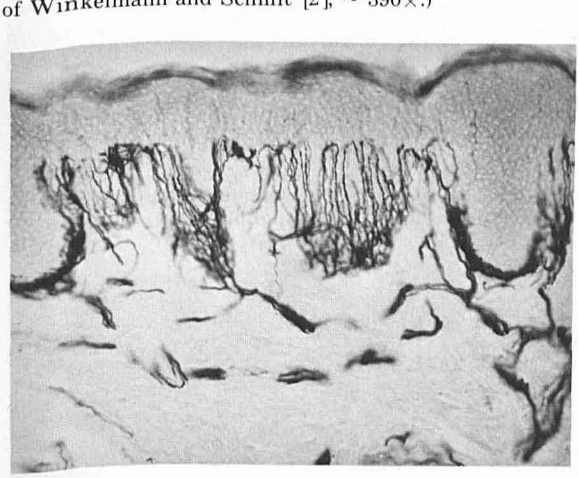

FIG. 7. Great numbers of acetylcholinesterase-reactive nerves at the bases of epidermal pegs in the rhinarium of a potto. Some intraepidermal nerves can be seen. (Modified cholinesterase method of Roman et al [3], ~ 125×.)

reactive masses, from which emerge single nerves or bundles of nerves. These masses are found underneath thickening of the epidermis which resembles häarscheiben; they are particularly numerous in the alae of the nose of *M. fascicularis* (Figs. 8, 9). Our techniques enable us to see some nonmyelinated neurites inside the epidermis; intraepidermal nerves are numerous inside the vestibule of the nares (Fig. 10). All of the follicles in the nose, inside or out, are profusely innervated. The only glabrous areas of the nose are the lower

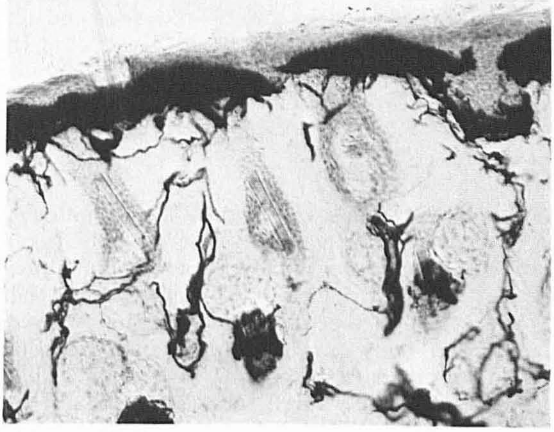

FIG. 8. Cholinesterase-reactive häarscheiben on the nose of the stump-tailed macaque (~ 125×).

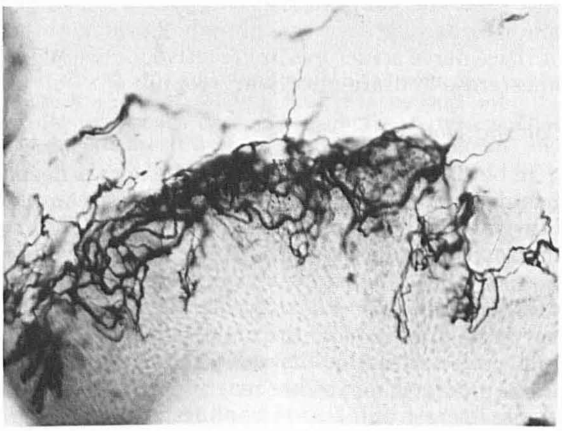

FIG. 9. Enlarged detail of a single häarscheibe to show its neural make-up (~ 210×).

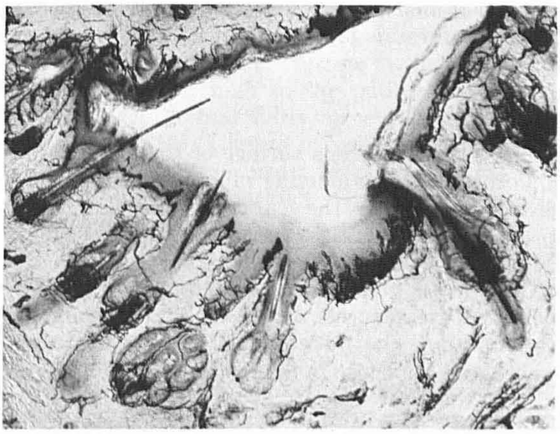

FIG. 10. Nerves around hair follicles, häarscheiben, and intraepidermal neurites in the choanae of a stump-tailed macaque (~ 54×).

(ventral) depressions of the choanae. Just lateral to the nose and along the labial borders are many very small sinus follicles, all heavily innervated [7]. Large sinus follicles are found primarily in the mystacial areas and above the brows. The innervation of the follicles of the muzzle decreases perceptibly at the periphery of the facial disc. All of the nerve elements described here can be demonstrated with the techniques used for both cholinesterases, and most are argyrophilic.

Man

Most of the follicles on the nose are so small as to be appendages of the large sebaceous follicles; in complex, they form a thick sebaceous blanket over the surface of the nose. Notwithstanding their small size, all of these follicles, like the others on the human body, are equipped with a sensory nerve end-organ (Fig. 11) [8]. Since all follicles elsewhere, large or small, are also similarly endowed, there is nothing unusual about the nose or facial disc. The terminal dilated ducts of the sebaceous follicles are also enwrapped with nerves and resemble häarscheiben (Fig. 12). Intraepidermal neurites are seen occasionally on the nose. All of these nerve structures are reactive for acetylcholinesterase and are mostly argyrophilic.

Cat and Dog

In both animals, the surface of the nose is deeply pebbled on the outer surface and has a complex labyrinthine structure on the underside. The few intraepidermal neurites that penetrate the epidermis of the rhinarium are patternless and are distributed singly (Fig. 13). The dense network of nerves that adheres to the underside of the epidermal projections, the expanded free ends, and the intraepidermal nerves are reactive for both acetylcholinesterase and butyrylcholinesterase, and they are also argyrophilic. The small dense hairs around the nose, lips, and muzzle are all well innervated as are some of the large ones as far as the periphery of the facial disc. Large, often luxuriant vibrissae extend from the mystacial areas and above the brows.

Rat

The small, glabrous surface of the rhinarium is smooth and the underside of its epidermis somewhat flat. As in the cat and dog, the short, intraepidermal neurites are sparse and patternless. Below the epidermis is a network of myelinated fibers and some free expanded endings. These elements are reactive for cholinesterases and are argyrophilic. The follicles of the muzzle are well innervated but those in the rest of the body are not.

Pig

The innervation of the snout and muzzle of the pig has been studied by a number of authors

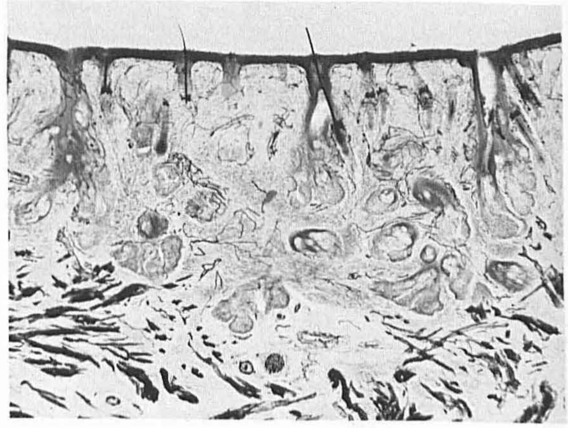

FIG. 11. Low magnification of the surface of the human nose in which the cholinesterase-reactive nerve end-organs can be seen around each follicle. (Acetylcholinesterase technique of Roman et al [3], ~ 19×.)

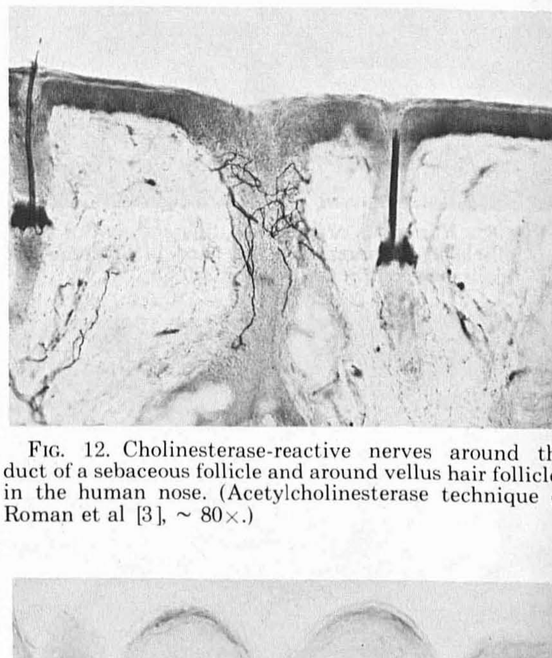

FIG. 12. Cholinesterase-reactive nerves around the duct of a sebaceous follicle and around vellus hair follicles in the human nose. (Acetylcholinesterase technique of Roman et al [3], ~ 80×.)

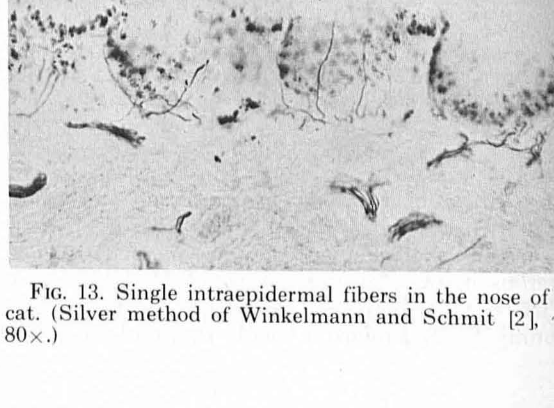

FIG. 13. Single intraepidermal fibers in the nose of a cat. (Silver method of Winkelmann and Schmit [2], ~ 80×.)

[6,9,10], but the observations that follow are unique. The upper part of the flat snout has a hard horny plate, thick and glabrous and adapted for routing. The surface of the funnel-like depressions of the expanded nares is also glabrous, but the flat of the snout between the flared nares is pock-marked with large orifices of sinus hair follicles from which emerge stout vibrissae of variable length; there are no ordinary follicles in this area. Throughout the entire snout the surface of the underside of the thick epidermis is specialized differently in the hairy and glabrous areas. Where the flat snout is hairy, each sinus hair follicle is surrounded by very long, narrow, concentric ridges; where it is glabrous, the underside presents a somewhat reticulated appearance, as described by Montagna and Macpherson [6].

Many large myelinated nerve bundles rise up to the long epidermal ridges in both the hairy and glabrous areas and before reaching the bases divide into neurites which form masses resembling end-organs and grouped at the bases of the epidermal ridges and inside the dermal papilla (Fig. 14). Fitz-Gerald [11] called these masses bulbous corpuscles. They are composed of glomerate skeins of nerves, easily demonstrated with silver methods. From the myelinated subepidermal nerves also emerge fine, parallel neurites, some of which go inside the epidermal ridges, and some penetrate the thin dermal papillae between the epidermal ridges (Fig. 15). Expanded nerves as well as intraepidermal and dermal papillae neurites are more numerous in the glabrous areas around the choanae than in the areas which contain sinus hairs. All the myelinated fibers and the expanded nerve end-organs are cholinesterase positive. All myelinated and nonmyelinated nerves described here are acetylcholinesterase reactive and argyrophilic.

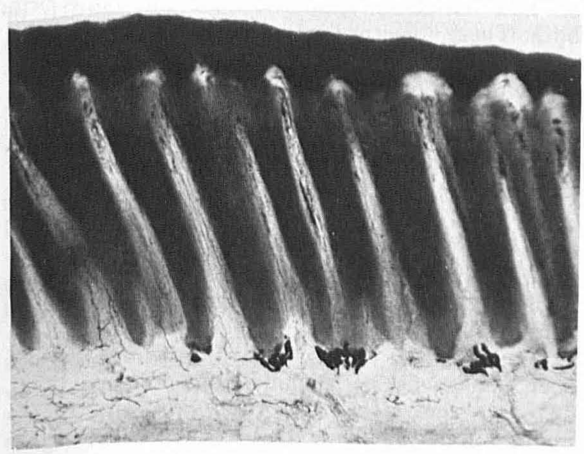

FIG. 14. Bulbous corpuscles from the snout of the pig at the base of the epidermal ridges and high up in the dermal papillae. (Silver technique of Winkelmann and Schmit [2], ~ 125×.)

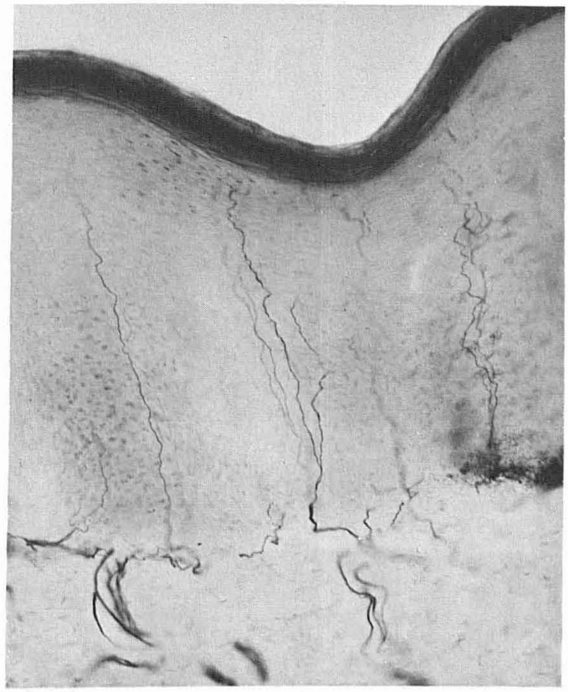

FIG. 15. Nerve trunks underneath the epidermis of the snout of the pig, sending branches upward into the narrow epidermal ridges and inside the dermal papillae between them. (Silver method of Winkelmann and Schmit [2], ~ 100×.)

Elephant

We have studied in detail only the prehensive lips at the tip of the trunk since elsewhere, whether in the trunk or facial disc, cutaneous nerves are sparse. Our limited search of the literature has yielded no pertinent reference. Under the epidermis of the tips of the truncal lips are numerous cholinesterase-reactive, small, encapsulated, Pacini-like corpuscles which resemble both end-bulbs (endkapeln), formerly called Krause end-bulbs, and the Grandry corpuscles found at the edge of the bill of ducks and geese [12]. These corpuscles are scattered singly or in clusters at the base of the epidermal ridges, high in the papillary body between the epidermal folds, or even deep in the dermis (Fig. 16). Chains of corpuscles are often connected by nerves from which spring variable numbers of neurites which rise into the dermal papilla and some of which penetrate the epidermis (Fig. 17). Those that remain in the dermis form glomerate skeins of argyrophilic nerves (Fig. 18).

DISCUSSION

The major organs of touch in all mammals are located principally in the face and specifically around the nose (in quadrupeds, the foremost part of the body), the mouth, and the eyes. Numerous sensory nerves are also found in the perineum, a

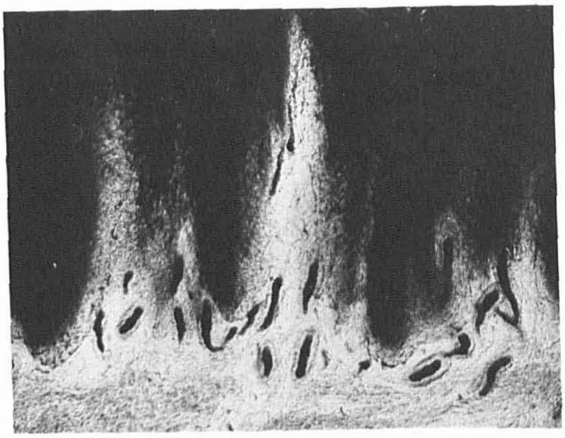

FIG. 16. Encapsulated Grandry-like or Pacini-like corpuscles in the trunk of an elephant. (Cholinesterase technique of Roman et al [3], ~ 80×.)

FIG. 18. Two Grandry-like corpuscles in the papillary dermis of the trunk of an elephant. Note their resemblance to mucocutaneous end-organs. (Silver method of Winkelmann and Schmit [2], ~ 125×.)

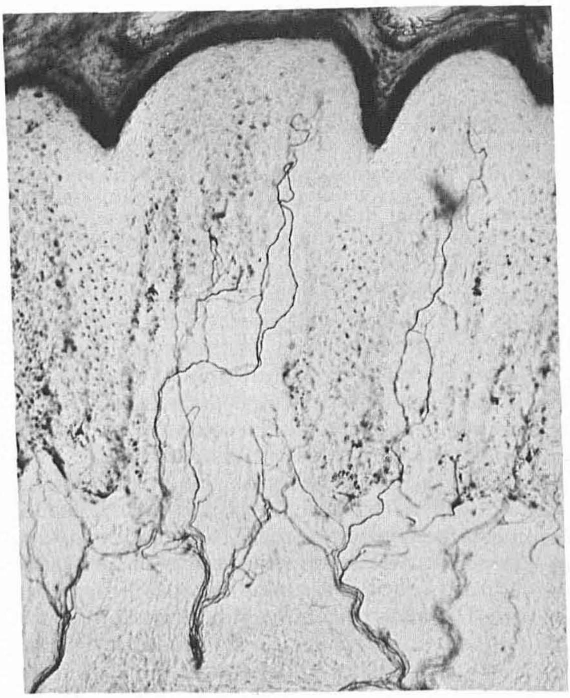

FIG. 17. Nerve trunks at the base of the thick epidermis in the trunk of an elephant divide into branches, some of which penetrate the epidermal ridges, some remain in the dermal papillae. (Silver method of Winkelmann and Schmit [2], ~ 100×.)

major erotic area, and at the distal parts of the appendages. The skin of hirsute mammals is insulated from the outside environment by a pelt of varied thickness and density; cutaneous sensory nerves, particularly those around hair follicles, are sparse and nearly negligible in these animals. The known exception is the mole, in which Giacometti and Machida [1] found a phosphatase-reactive end-organ around nearly every follicle. (Our own investigations support this finding, but the follicles of body hairs have only a very few nerves around them.) Among the many peculiarities of man, then, are his hair follicles, which though mostly archaic, have a well-developed nerve end-organ; the entire follicle is literally enwrapped in a complex nerve net [8]. Thus, despite the lack of comparative data, human skin is indubitably more sensitive than that of any other mammal.

These findings suggest that the high development of the sensory mechanism of touch around the primary sense organs of the facial disc has the special mission of protecting this most important and most vulnerable part of the body. Not all mammals with similar life styles, however, acquire the same degree of tactile sensation even though their mechanisms are morphologically similar. In nocturnal animals, for example, vibrissae are extremely large in opossums, cats, and rodents but small and sparse in moles. We find that the animals with small vibrissae have more numerous intraepidermal nerves and a richer innervation of all hair follicles around the nose and mouth or both. These structural mechanisms, together with data on human beings [13], lead one to infer that tactile sensory mechanisms have the lowest threshold on the facial disc and that the nerves we have just described are the morphologic receptors of the modalities of touch.

We have also shown that intraepidermal nerves exist in mammalian skin, at least in specialized areas [4,6,14]. Even in man they are more numerous than had been suspected; we have found them to be especially plentiful in mucocutaneous and friction surfaces.

Long-snouted, nocturnal, or burrowing animals such as hedgehogs [15], moles [1], opossums [4–6,15], tree shrews [6,16], lorises [17], and others abound in nerves inside the peg-like thickenings of epidermis that correspond to the elevation on the surface of the rhinarium. Such neurites originate directly from chalice-like configurations of myelinated nerves around the base of the epidermal pegs and not from "tactile disks" as Winkelmann [18] reported. We found no "tactile disks," only expanded free nerve endings. The intraepidermal neurites, together with the nerve baskets from which they arise, form clearly structured sensory end-organs which resemble Eimer corpuscles, and we suggest that they be so designated since, despite species modification, they all have basic similarities.

The particular configuration of the nerves of Eimer corpuscles in the mole is achieved by the centripetal bending of the lateral intraepidermal neurites. This suggests that some factor(s) in the epidermis provides a more satisfactory environment for fibers in the center of the epithelial columns than at the sides. This pattern, conspicuous in moles, is also observed in opossums, tree shrews, and lorises where the longest neurites and their greatest concentration are in the center of the epithelial columns.

Intraepidermal nerves are most often found in glabrous skin and are particularly numerous in areas where recognizable sensory end-organs are few or absent. On the muzzle, where most hair follicles have rich nerve end-organs, and the friction and mucocutaneous end-organs are plentiful, intraepidermal nerves are few. This can be verified in the snout of the tree shrew: here the hairs around the rhinarium are sparse, and single or tufts of neurites penetrate the epidermis. More laterally, where hair follicles grow densely, intraepidermal neurites are seldom encountered. In the choanae of man and other Cercopithecoid primates, where hairs emerge on the semimucosal membranes, intraepidermal nerves and mucocutaneous end-organs are numerous.

The function of intraepidermal nerves can be deduced from their location in the epidermis in areas of great cutaneous sensibility. This circumstance must be more advantageous to nocturnal, routing, and burrowing animals than to diurnal ones whose movements are largely aided by vision and whose hair follicles in these areas are equipped with sensory end-organs. The presence of such numerous end-organs around the follicles of the hairlets in human skin is not surprising since the human nose is known to have one of the lowest thresholds for pressure, point and two-point discrimination of any part of the body [13].

In contrast with the naked rhinarium of prosimians, the nose of simian primates is always hairy. Here nerve endings usually found in glabrous areas are present, together with hair follicle end-organs. The nose of macaques, at least, is unique in having many häarscheiben present. Those interested in the anatomy and physiology of these structures would do well to study them there.

This study has shown that the distribution of cutaneous sensory organs in the facial disc represents a strategic plan. This plan is to guide the animal in moving about without the aid of vision and to make it aware of disturbances that might be injurious to the other sensory organs.

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